HAWAII AGRICULTURAL EXPERIMENT STATION
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PAPAYA CULTURE IN HAWAII

By

W. T. POPE
Senior Horticulturist

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CONTENTS

INTRODUCTION

Papaya (*Carica papaya*) investigations have been conducted at the Hawaii Agricultural Experiment Station since 1902. During the past eight years the investigations have been confined principally to a determination of the cultural requirements and methods of improving the species. Completion of the work has been greatly retarded because of the unsettled habits of the plant. Its tendency to exhibit marked variations in nature and growth of fruit was observed in other countries by Correa de Mello and Spruce (*15, p. 11*)[1] in 1869, by Forbes (*7, p. 313*) in 1879, by Solms-Laubach (*18*) in 1889, by Iorns (*10*) in 1908, and by Kulkarni (*12*) in 1915. Wells (*22*) in 1906 published a general article on the papaya in Hawaii, and Higgins and Holt (*9*) in 1914 reported the results of crossbreeding the papaya at the Hawaii station.

This bulletin, which supplements and brings up to date the previous bulletin of the Hawaii station by Higgins and Holt (*9*), has been prepared to meet the demand for information on practical ways of growing the papaya in Hawaii and elsewhere.

1 Reference is made by italic numbers in parentheses to Literature Cited, p. 39.

HISTORY AND DISTRIBUTION

The papaya is a native of tropical America. The exact place of its origin has not been determined. Popenoe (*16, p. 228*) calls attention to considerable evidence indicating that the species originally came from Mexico. Solms-Laubach (*18*), who devoted much time to a study of the species and monographed the order Caricaceae, believed that the cultivated papaya originated as a cross between two species of the genus Carica native to Mexico. Probably the earliest published mention of the papaya was made by the Dutch traveler, Linschoten (*16, p. 225*), in 1598. He states that the plant was taken from the Spanish Indies (West Indies) to Malacca and transported thence to India. According to him the papaya was designated as "papaios," and his description leaves no doubt as to its identity. From either the Philippines or Malacca the papaya is believed to have spread rapidly by means of the seeds to many islands of the tropical Pacific. Sturtevant (*19, p. 142*) indicates that the papaya had been widely spread in the Pacific islands by 1800. Ellis (*5, v. 1, p. 66*) mentioned the papaw apple (*Carica papaya*) as growing abundantly in Tahiti. During a trip around the island of Hawaii in July and August, 1823, he (*5, v. 4, p. 25*) also observed that the papaw apple was grown among other fruits and vegetables by the Hawaiians. Several old-timers in Hawaii, including Thomas G. Thrum, of Honolulu, who came to the island from Tahiti in 1853, state that the papaya was commonly grown in these islands in the early fifties. Mr. Thrum says that the papaya, which he had also seen growing in Tahiti, was in common cultivation in Honolulu, and calls attention to the Hawaiian name of the papaya, he-i,[2] which from its nature indicates that the fruit was in use before the discovery of Hawaii by Englishmen in 1778. The papaya was also known as milikane, another Hawaiian name. The papaya evidently was introduced into Hawaii at an early date, for the original inhabitants did not ordinarily give Hawaiian names to newly introduced fruits but adopted the English name, sometimes with some modification as to sound.

NOMENCLATURE AND BOTANICAL RELATIONSHIPS

In Hawaii and other parts of the United States, the name papaya is now generally applied to *Carica papaya*. Many other English-speaking countries use the term papaw, which in North America has long been applied to *Asimina triloba*, a wholly unrelated species. DeCandolle (*2, p. 293*) concluded that the common name papaya is a corruption of the Carib word ababai of the original American Indians. Popenoe (*16, p. 228*) says that papaia, papeya, and papia are some of the corruptions in use. The papaya also has many other different common names in the various countries in which it has been introduced. It also has several different botanical names, but *C. papaya* Linn. is now generally accepted. In botanical classification the genus Carica belongs to the small family Caricaceae. The generic characters are such that botanists have at different times classi-

[2] The papaya has very similar names in other Polynesian dialects. In Samoan it is known as eti; in Tahitian, as iita; in Fijian, as esi; and in Marquesasan, as vi.

fied it with the families Passifloreae, Cucurbitaceae, and Papayaceae, and by some authorities it is still placed in the last-mentioned group.

A number of other related species of Carica grow mainly in the wild state in different parts of the Tropics. None of them, even under cultivation, produces fruit which compares with that of *Carica papaya*, but they may prove to be of value in papaya-breeding experiments.

C. candamarcensis, the mountain papaya of Colombia and Ecuador, is described by Popenoe (*16, p. 240*) and by Wilcox (*24, p. 119*) as a small tree with cordate, palmately 5-lobed leaves and small yellow 5-angled fruits about 3 or 4 inches in length. In flavor the fruit is too acid to be used as a dessert, but it may be stewed or made into jam and preserves. *C. candamarcensis* is also described and illustrated by Macmillan (*14, p. 274–275*).

FIGURE 1.—Pistillate plant of purely dioecious type, commonly called "round-fruited" papaya

The plant of *C. erythrocarpa* is similar to that of the papaya, but the fruit has thin red flesh, which has sometimes been considered as particularly useful in the production of papain (*24, p. 119*).

C. quercifolia attains a height of about 5 or 6 feet and has oaklike leaves and clusters of small yellow ellipsoid fruit 1 to 2 inches long with five longitudinal stripes that change from white to yellow as it ripens.

C. gracilis is a small, slender, ornamental from Brazil. It has compound leaves, 5-digitate, each leaflet having wavy indentations, the middle leaflet being 3-lobed (*1, p. 664*).

DESCRIPTION

At least two leading types must be taken into consideration in a general description of the papaya. These are based upon such

simple characters as arrangement of inflorescence and form of fruit by means of which the types may the more easily be identified. In Hawaii the types are commonly designated as dioecious or round-fruited (fig. 1) and monoecious or long-fruited. (Figs. 2 and 3.) The Solo papaya (fig. 4) is in reality a strain of the dioecious type. None of the three kinds are correctly designated by the above-mentioned terms inasmuch as they exhibit numerous variations of sex forms in the flowers and differences in size and shape of fruit. This subject is discussed more in detail under Variations, p. 10.

FIGURE 2.—Monoecious type of long-fruited papaya. This form of fruit is well adapted for marketing

The papaya is a large herbaceous plant which at maturity may attain a height of 25 or 30 feet. It is sometimes called a tree and is also likened to a palm, but it is not botanically related to the palms. In structure the papaya is dicotyledonous, the trunk is hollow, and the wood fleshy. Normally the trunk is erect and while young usually consists of a single shaft. (Fig. 5.) After two or three years of growth it may develop upright branches, each of which tapers to a terminal containing a cluster of leaves. (Fig. 6.) The bark is smooth and grayish, and is marked by prominent leaf scars. When cut or scratched, the outer surface freely yields a thin milky juice. Ordinarily the plants are short-lived, and after three or four years the growth slows down, and the leaves and fruit diminish in size. At this stage, the plants soon die or are removed by the grower to give place to more profitable crops. Papaya plants when grown under very favorable conditions,

however, have been known to live for 15 to 20 years and to produce satisfactory fruit during a part of this time. (Fig. 6.)

The foliage of the papaya consists of a crowning cluster of large leaves at the terminal of trunk and branches. New leaves are almost

FIGURE 3.—A good marketing type of papaya 15 inches long and weighing about 8 pounds

constantly forming at the top of the cluster, and as the stem shoots upward the older leaves mature and fall. This process gives space for the developing fruit. The normal period of life of a leaf is usually but a few months, depending somewhat upon the rapidity

of growth of the plant. The maturing leaves of the Carica species form a natural abscission in separating from the trunk, leaving well-defined leaf scars. The leaves of vigorous, 1-year-old plants are 2 feet or more across. The soft smooth blades are palmately 7-lobed, each lobe being pinnatifid and pointed, dark green above, and light green below, with conspicuous venation. The cylindrical leaf-stalks are stiff, smooth, hollow, reddish brown above, greenish below, and from 2½ to 3⅓ feet long.

FLOWERS AND FRUIT

The flowers on the staminate or male plant of the dioecious types are sessile, and are borne in clusters on long pendent racemes 3 feet or more in length. In the individual flowers the corolla is tubular or somewhat funnel shaped, about an inch long, and divided into five spreading and slightly twisted petals of a creamy white or yellow color. (Fig. 7.) The flowers emit a pleasant nasturtiumlike fragrance. Ten stamens, which are arranged in two series, occupy the throat of the corolla. The filaments are hairy, the anthers are oblong, and 2-celled, and the pollen grains are abundant, oval in outline, and yellow in mass. In most of the staminate flowers there are only rudiments of the pistil, but occasionally a flower cluster develops one or more flowers which produce fruit. (Fig. 8.) These changes are discussed in some detail under Variations, p. 10.

FIGURE 4.—Solo papaya of the round-fruited form. This strain has a delicious flavor

The flowers on the pistillate plants of the dioecious type are subsessile, are borne along the trunk in the axils of the leaves, and are usually solitary or in few-flowered corymbs. The flowers are considerably larger than the staminate kinds. They have five rudimentary sepals and five fleshy petals that are united toward the base. The ovary is large, globose or slightly cylindrical, with the apex terminating in five sessile fan-shaped stigmas.

The fruit in general characters strongly resembles a muskmelon. (Fig. 9.) It ranges in weight from 10 ounces to 15 pounds, is spheri-

cal to oblong, and in some instances is composed of five longitudinal sections. (Figs. 10 and 11.) The skin is thin, smooth on the exterior, and yellow to deep orange in color; the flesh is yellow to deep orange, is 1 to 2 inches thick, and envelops a large, somewhat 5-angled cavity, attached to the walls of which are numerous round, wrinkled, black seeds the size of small peas inclosed in a thin gelatinous aril. (Fig. 9.)

The Solo papaya is a strain or so-called variety the description of which was probably first published by Higgins (*8, p. 28*) in 1919. At this time it was given the name "Solo" presumably because each fruit is large enough to serve one person only. The Solo papaya has continued to grow in popularity and is now known to a great many persons in Hawaii and also in many other parts of the world where papayas are grown. To keep the seedling strain pure, it must be grown in isolation. At the Hawaii station this strain, even when grown in a field an eighth of a mile distant from other papayas, was noted to have become cross-pollinated with other kinds and to have lost its identity as a Solo both in flavor and appearance of fruit. It is here described along with the so-called round-fruited, dioecious type of larger fruit because the Solo plants of recent years growing at the station are practically all of this type. The present planting, not greatly unlike that of several previous years, contains 46 plants, 10 of which are staminate and the rest pistillate, without any hermaphrodite forms among them. Hermaphrodite or bisexual forms are said to have predominated in the Solo variety previous to 10 years ago. The plants are small and the trunks slim. They usually require about 18 months' growth from seeds to come into bearing, and the fruit does not set low as with most other kinds of papayas, but begins to develop at about 3 feet from the ground. (Fig. 4.)

FIGURE 5.—Papaya plant of good form—erect, vigorous, and prolific. The stake is 36 inches high

The Solo fruits of the pistillate plants are small but numerous, and the yield per plant is considered to be abundant though not equal in weight to that of the plants of the larger fruited kinds. The Solo fruits weigh from 10 ounces to a pound and are mainly of two shapes, pyriform and spherical. (Fig. 12.) The two forms occurred separately on different plants for many years at the Hawaii experiment station, but lately it has not been uncommon to find them more or less mixed on the same plant, notwithstanding the fact that the seed producing such plants was selected from pyriform fruit. (Fig. 17.) The skin is smooth and free from blemishes and decaying spots which occasionally are found on other kinds of thoroughly ripened papayas. The skin is bright yellow to orange in color, and the flesh is

FIGURE 6.—Part of an old grove, probably 15 years old, still fruiting. Trunk and branches are tapering, and fruit and foliage are small

of medium thickness, rich golden yellow, smooth, tender, and of a sweet and cresslike flavor.

The monoecious or long-fruited type is sometimes called "Elongata." In general appearance the plant is similar to the pistillate plant of the dioecious type, but the inflorescence is usually hermaphroditic, possessing both staminate and pistillate organs. The irregularities of inflorescence are discussed under Variations, p. 10. The inflorescence consists of short flower clusters about 3 to 5 inches long. Each cluster is from a separate leaf axil and contains about six almost sessile flowers. The individual flower is 1½ to 1¾ inches long, and has a tubular base which widens into goblet shape and then spreads into five thick, recurved petals of a cream or yellow color. (Fig. 13.) The 10 sessile anthers are attached to the throat of the corolla near the base of the petals. Usually only 1, 2, or 3 of the flowers of a cluster have stigmas sufficiently perfected to receive pollen for fertilizing the ovules and thereby developing the elon-

FIGURE 7.—Flowers of dioecious papaya: *a*, Cluster of staminate flowers; *b*, pistillate flower; and *c*, small fruit

gated ovaries into fruit. (Fig. 11.) Often the young fruit is not released from the corolla tube for several days after fertilization. Such fruit has a peculiar shape with a somewhat cylindrical basal portion which persists throughout the development of the fruit to maturity. (Fig. 14.) The mature fruits reach a length of 12 to 18 inches, have a weight of 6 to 10 pounds, are usually of good flavor and have better shipping qualities than the more spherical forms of fruit of the dioecious kind. (Fig. 3.)

FIGURE 8.—Plant with mostly male flowers, some of which were perfect and produced fruit on long pendent stems

VARIATIONS

The numerous and unusual variations of *Carica papaya* are not only perplexing to the layman, but have proved to be confusing to the botanist and the horticulturist. The causes of these variations may be grouped as environmental or hereditary.

Environmental causes include conditions of soil, moisture, temperature, and location, and possibly a combination of any or all of these factors. The results may be dwarfness, unusual vigor, prolificacy, or stunted growth of the plants. The results may be also a variation of fruit as to form, color, texture, fragrance, and flavor. Contrary to natural methods, parthenocarpic fruits occasionally appear. These are seedless fruits, probably produced without sufficient stimulus of pollination to develop viable seeds, a condition noted also in such other fruit plants as the seedless bananas, and some varieties of oriental persimmons, vinifera grapes, and navel oranges. Seedless papayas are usually inferior to papayas that are produced normally, the flesh being thin and insipid. (Fig. 15.) Plants producing seedless papayas have been observed to drop most of their flowers probably because of failure of cross-pollination. This

is usually due to the almost continuous blowing of misty rain during the receptive stage. The wind prevents pollen-carrying insects from working, and the rain moistens the pollen to such an

FIGURE 9.—Oblong fruit showing arrangement of seed in cavity

extent as to make it too heavy to be carried to the pistillate trees by the wind. Stunted growth is often noticed in neglected papaya plants which have been subjected to a period of insufficient moisture. Although the papaya is somewhat tolerant of such abnormal condi-

tions, it may die when the drought is prolonged. Sections of the trunk of plants the normal growth of which has been retarded in this manner for a short period will be found to remain small as if they were constricted, and the internodes will fail to lengthen naturally. From these conditions the papaya plant can not recover. Growth may be stunted without dropping of the flowers or young fruit. Giving the plant a renewed supply of nourishment will cause it to produce crowded and dwarfed fruit which may burst and decay before it has had a chance to reach usable size. (Fig. 16.)

FIGURE 10.—Papaya with roundish fruit which has longitudinal sections that give it somewhat the resemblance of the muskmelon

Hereditary variations may appear as a recurrence of some form of ancestral characters, or they may be new combinations from the direct influences of crossbreeding in the previous generation. Such variations are complete or partial changes in the inflorescence, particularly in the essential organs of the flowers, and may result in variation in form, color, odor, and flavor of the fruit. The influences of variation are also evident in the growth of the plant.

The most remarkof all of these hereditary irregularities is shown in the distribution of the sexes and their peculiar variations from time to time. In the inflorescence of the species may be found not only the three well-known floral forms, dioecious, monoecious, and polygamous, ascribed to plants in botany, but also a number of other sex combinations with which the papaya grower should familiarize himself.

Staminate plants apparently have the greatest number of variations. The younger staminate plants are distinguished from the pistillate forms by the appearance on them of long-stalked inflorescence. (Fig. 7.) Normally, the flowers are purely staminate, each with a rudimentary pistil, but occasionally a flower cluster will develop one or more flowers which produce fruit. This may occur dur-

ing the first year, but usually it takes place after several years of growth. Some of the staminate plants at the Hawaii station have produced a few fruits in their second or third years only, although they lived for four or five years afterwards. Old plants occasionally develop the greater number of fruit-producing flowers. A plant under the writer's observation for more than eight years has been found to be a continuous producer, bearing a cluster of 20 to 60 developing fruits at a time. The fruits are usually uniform in shape, oblong, about 7 or 8 inches in length, and weigh about a pound. (Fig. 8.) The flesh is pale yellow and of inferior flavor. The seeds are indistinguishable from those of other papayas. The fruits are easily identified as to the kind of plant producing them, and locally they are commonly called male papayas. In an experiment at the Hawaii station in 1923 the seeds of one of these papayas were planted in a propagating box in the usual way and gave a good percentage of germination. Some of the plants were selected at random and were set in an experimental row, where they remained until the latter part of 1926. In the cool season of 1924–25 they came into flower. Fifty-seven per cent had normal staminate flowers, whereas the rest produced normal pistillate flowers and fruit common to the dioecious type. This was the only experiment of the past eight years in which seeds of the male tree were used.

FIGURE 11.—Papaya plant. With the extension of the trunk the fruit is changing from long spindle shape to oblong with distinct five longitudinal ridges

Higgins (*8*, *p. 20*) states that fruit-producing staminate plants were first described by Correa de Mello and Spruce (*15*, *p. 3*) and named the "correae form" in honor of the former. A study of the papaya flower at the station indicates that these fruiting staminate plants are not distinct sex forms but only variations of certain staminate flowers in which the rudimentary pistil becomes perfect and produces fruit. Results of experiments made at the station

previous to 1920 show that the so-called "male fruit" from the staminate plants of dioecious form will also produce monoecious and polygamous plants. This has led to the belief that the long-fruited monoecious and polygamous forms originated from these plants. Plants of these same sex forms have also developed from the seed of the purely pistillate dioecious form.

During the past eight years efforts have been made at the station to improve the dioecious papaya by seed selection and good culture. As a result the quality of fruit has been generally improved. During this time the fruit-bearing plants have considerably exceeded the staminate plants in number. The staminate plants constituted 36 per cent of those that began fruiting in the field in 1924 and 51

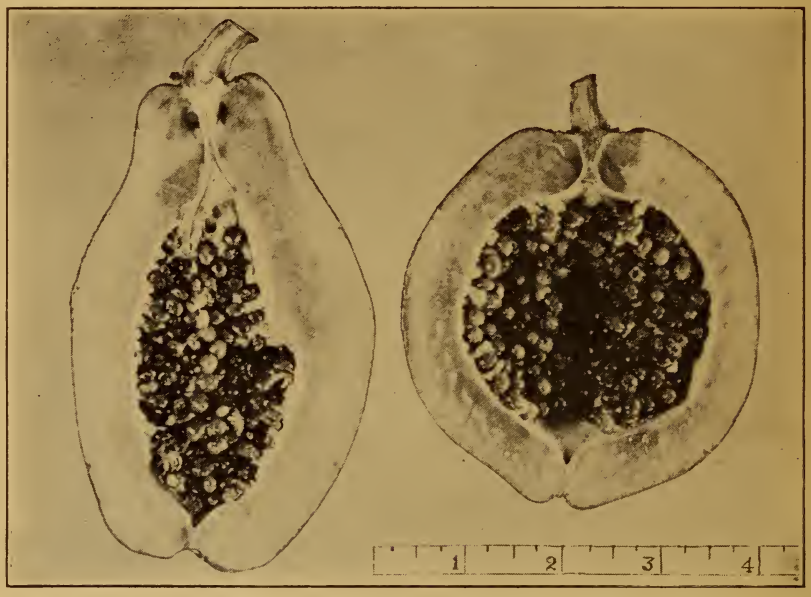

FIGURE 12.—Pyriform and spherical-shaped fruit of the Solo papaya

per cent of those growing on a very small area and fruiting for the first time in 1927.

Change of shape of fruit on the plants of an entire field occasionally takes place. A fair instance of this occurred in an experiment at the station during the season of 1923–24. The plants were produced from the seed of a long fruit of the monoecious type as represented in Figure 3. All the fruits were true in form to the parent type during 1923. The following summer, however, the same plants bore large spindle-shaped fruit with diameters equal to about one-half or more of their respective lengths. It was suspected that cross-pollination had influenced these variations direct, but results of a cross-pollination experiment in a near-by field at the station in the fall of 1924 failed to show that change of shape of fruit is caused by the stimulus of cross-pollination.

Often individual plants may bear fruit only a part of which is of unusual form. These variations take place in both the pistillate

plants of the dioecious type (fig. 14) and the long-fruited or monoecious type. (Fig. 11.) These variations also occasionally occur in the Solo strain. (Fig. 17.)

A peculiar variation of the papaya not uncommonly takes place in the formation of small papayas in the true fruit. Sometimes each malformed small fruit contains seed and appears to have a stigma, but usually it is imperfect in form and seedless. These freaks are believed to be due to an overstimulative effect of pollination in which more than one ovary is fertilized and abnormal fruits attempt to develop in the normal fruit. (Fig. 18.)

A pistillate-flowered plant of the dioecious type sometimes changes the form of a part of its flowers. A number of examples have been noted at the station. In one instance a plant produced purely pis-

FIGURE 13.—Flowers and young fruit of the Elongata type. The flowers are monoecious—capable of self-pollination

tillate flowers which were followed by smooth, almost-roundish fruit, as shown in Figures 1 and 7. A few long-tubed flowers with seemingly perfect stamens and pistils began to appear among the fruit. (Fig. 19.) These flowers were followed by long fruit of the typical monoecious type. As the fruiting section of the trunk extended, another form of flowers, apparently perfect in most part, developed. These were of the kind in which one-half of the stamens, five in number, develop to a considerable length and lie in longitudinal creases, as shown in Figure 20. These flowers developed short fruit with five longitudinal sections or lobes. All three forms of fruit were found on the plant at the same time. (Fig. 14.) A somewhat similar condition was observed in the Solo papaya. Some of the plants produce pyriform fruit, others almost spherical or 5-lobed fruit, and occasionally a plant produces both of these forms of fruit at the same time. (Fig. 17.) An unusually wide range of difference

was noted in 1922. The fruits of two plants of No. 4610 [3] from the same supply of seed were widely different in shape, texture, thickness of flesh, and flavor. One was nearly spherical, of orange-colored flesh, medium thickness, and good, sweet flavor (fig. 21); the other was oval-oblong, of very thick, light-yellow flesh, and poor flavor. (Fig. 22.)

FIGURE 14.—Several different forms of fruit on the same plant. The fruits also vary in flavor

An interesting variation occurs occasionally in the long-fruited monoecious type, which, if it could be established as a true variety, would probably have certain local advantages in shipping and serving qualities. This variation, like that of many other papaya plants, occurs mainly in the form of fruit. It differs from some of the other long types in being comparatively free from the corolla tube during the very young growth when the ovary is developing immediately after fertilization in the flower. The petals are divided to or nearly to, the base of the corolla tube and soon fall away after pollination without restricting the ovary, as is the case with some of the longer tubed flowers, which are described elsewhere. (Fig. 14.)

At maturity the typical fruit of the variation is long and cylindrical, a fact which has to some extent given it the local name of "cucumber papaya." The cucumber papaya is 12 to 18 inches long by 2½ to 4½ inches in diameter, and tapers somewhat toward the base, and is usually pointed at the stigmatic end. The flesh is thick, orange in color, firm in texture, and generally of good flavor. The central

[3] Station accession number.

cavity is usually quite small, and often in the smaller fruit is entirely filled with seeds. The prolific plant is unusual in its appearance. (Fig. 23.)

Color variations of the fruit of the papaya are not unusual. In 1922 the writer observed two fruits of oblong-pyriform shape and of slightly different color and shape from those of the other fruits on a pistillate plant of the dioecious kind growing in a papaya trial plat at the station. These fruits were heavier than other fruits on the same plant, probably because of their thick flesh, which was also of unpleasant odor and flavor and not at all like the other yellow-fleshed fruits of the same plant. (Fig. 24.) No seeds of reddish-

FIGURE 15.—A seedless papaya produced without pollination. Such fruits usually fall early and those that do mature are poor in flavor

fleshed papayas had been planted at the station during the several years previous. Another example in color variation was observed in 1925. In 1924, S. C. Warner, of 1548 Meyers Street, Honolulu, was given a reddish-fleshed papaya from a near-by garden. The seeds of this fruit produced three plants. The next year two of them produced red-fleshed fruit and the third the usual orange-fleshed fruit. Mr. Warner brought one of the reddish papayas to the station. The flesh was of a deep crimson color and was of excellent flavor. The seeds were germinated, and 185 of the resulting plants were brought into fruit in 1926. A large percentage of them bore fruit, most of which had the ordinary yellow or orange flesh, a few had flesh of a pale pinkish color, but none had the crimson color of the fruit whence the seed came. None of the fruits of any of the plants in this experiment was of a particularly desirable flavor. The last

two examples in fruit variations indicate that color, flavor, and odor characters are to some extent hereditary. The papaya, like various other kinds of plants, has mutating characters which reoccur and predominate rather unexpectedly. The orange-fleshed fruit contains red pigments which occasionally develop in multiple form, and give the red color in place of the orange.

FIGURE 16.—Crowded and dwarfed fruit and constricted trunk growth resulting from prolonged drought

SEX DETERMINATION AND IRREGULARITIES

The problem of sex determination in the papaya has led to considerable speculation. For some years claims have been made that the sex of the future plants can be determined before the appearance of the blossoms. In many instances it has been stated that pistillate plants develop from seeds taken from certain portions of the cavity of the fruit. Occasionally it is reported that fresh seeds producing pistillate flowers can be accurately separated by their appearance from those producing plants with staminate flowers, and, likewise, that pistillate plants can be successfully identified during the first few weeks of their growth previous to being set in permanent place. Investigations were made at the station to determine whether this was true. In one experiment, carried on from 1922 to 1924, 72 plants were grown from seeds of one oblong papaya, 36 of the seeds being from the portions of the cavity at the basal or stem end, and the rest from toward the stigmatic end of the cavity. The seeds of each section gave a large percentage of pistillate plants, but no evidence was obtained to show that the seeds

of one section produce plants entirely of one sex or even an unusually large percentage of one sex. In a second experiment, begun in 1927, the seeds used were taken from the fruit of a normal pistillate plant of dioecious type. This fruit was cut crosswise into three equal parts, and the seeds of each part were respectively designated as basal, medial, and terminal. Each of the three kinds of resulting young plants were set separately in three rows. When the plants came into flower there were staminate and pistillate forms of the purely dioecious type, and monoecious and polygamous forms, and also one apparently monoecious form which was sterile, since it blossomed but failed to set fruit. Results of this experiment, like those of the former, indicated that seeds capable of producing plants of a particular sex are not confined to any one part of a fruit.

FIGURE 17.—The Solo strain produces two forms of fruit, but generally retains the desirable flavor characteristic of the strain

Only one experiment was conducted at the station to determine the ability to select from a fresh fruit such seeds as will produce a definite sex of the papaya. In 1926 the station received two small packages of papaya seeds from G. P. Wilder, of Honolulu, who was visiting in Tahiti, Society Islands. In his presence these seeds had been sorted out of a ripe papaya by a gardener from Anam who claimed that he could determine the sex of the dioecious type from the appearance of the individual seeds. He separated the seeds into two groups which he designated as "he's" and "she's". These seeds were grown at the station in separate rows, and the plants flowered in the early part of the summer of 1928. All the "he's" proved to be staminate but one; likewise, all the "she's" were stami-

nate. The results failed to show that papaya plants of a definite sex can be selected in the seed. The writer has not learned of a

FIGURE 18.—Small deformed papayas sometimes develop in the normal fruit

single substantiated instance of anyone's being able to determine the sex of young seedling papayas previous to the appearance of the inflorescence.

FIGURE 19.—Flowers and young fruit from the same plant; several sex forms are present. Some of the modifications produce deformed fruit as is here shown

Investigations show that most of the sex forms are not constant, that one may assume the rôle of another, and that most of these changes take place without apparent cause. (Fig. 14.) Such an

unusual change as a sterile plant coming into bearing (fig. 25) or a staminate plant developing fruit among the long clusters of

FIGURE 20.—The pistillate flower sometimes becomes staminate bearing; five stamens develop and possibly cause the five divisions in form of fruit

FIGURE 21.—The plant producing this fruit of excellent quality was an unusual variation, as the fruit of other plants of No. 4610 were poor in quality. (See Table 2.)

male flowers after having been shocked by some accident, as when the top is broken off, have probably led to the conclusion that a change of sex may be induced by either topping or root pruning

the plant. Iorns (*10, p. 125*), who studied the question in Porto Rico, reached the conclusion that other conditions than the loss of the terminal bud must be present to induce a change of sex. Kulkarni (*12, p. 103*), from investigations in India, came to the conclusion that change in sex is not in any way connected with the removal of the terminal growth. He found that the male plants in the course of their development may present a number of different sex combinations, practically all of which have since been observed at the Hawaii station and are described in this bulletin.

FIGURE 22.—Papaya with thick flesh, a good type for general use if desirable flavor can be maintained. This form is not an unusual variation

On several occasions during the past eight years at the Hawaii station a number of staminate plants have been topped in an effort to change the sex, but in no instance has it been successful.

METHODS OF PROPAGATION

The papaya is propagated from seeds and by cuttings and grafts. Reproducing the plants from seeds continues to be the best and most commonly practiced method of propagation. Plants of both cuttings and grafts have been grown to full maturity at the station, but none of them has been found to be vigorous or prolific in com-

parison with seedlings. It was further observed that papaya plants which were propagated vegetatively failed to reproduce varietal fruit characters, such as size, shape, texture, and flavor, like those of the parent plants from which the cuttings and scions were taken. Some of them proved to be as variable as seedlings. Various methods of propagation, like planting, may be accomplished at almost any time of the year in Hawaii. The several forms of vegetative propagation do best in the cooler months while germinating seeds and young seedlings possibly develop best in spring.

FIGURE 23.—Among long-fruited papayas occasionally occurs a slightly different strain locally called the "cucumber papaya" and possessing a very small cavity

SEEDS

In the successful cultivation of the papaya, a quick and uniform germination of a large percentage of the seeds planted is important. To accomplish this, special attention is required, such as is often employed in the development of seedlings of many other kinds of cultivated plants. Seeds of mature fruit when washed, dried, and stored in well-capped glass jars will retain their vitality for several years. For convenience in this work at the station, the germinating flat was used. It consisted of a shallow box having either spaces between the bottom boards or small holes bored in them to provide for drainage. Such a flat should be about 14 inches wide and 18 inches long and 3 to 5 inches deep. A 2½-inch layer of rich, light, preferably sterilized, soil that had been run through a sieve, was then placed in the flat. This soil was leveled and firmed, and the seeds were sown upon it about one-half inch apart. They were then covered with a one-half inch layer of washed coral sand. Given a suitable medium of temperature[4] and moisture, papaya seeds germinate in 10 to 15 days. The coral sand permits the air to cir-

[4] The average summer temperatures (July) at the station are about 79° F. during the day and 75° at night. January temperatures average about 7° lower.

culate freely in the box and tends to prevent the development of damping-off fungi, which are destructive to many kinds of young seedlings. A top-dressing of coarse, black volcanic sand was used successfully at the station in place of the coral sand. After three to four weeks the seedlings should be of suitable size for transplanting to 4-inch pots. (Fig. 26.) They may be kept in these for three or four weeks longer before being transplanted to their permanent place in the orchard. The seedlings should be protected against unusual temperatures, wind, insect attack, and the like.

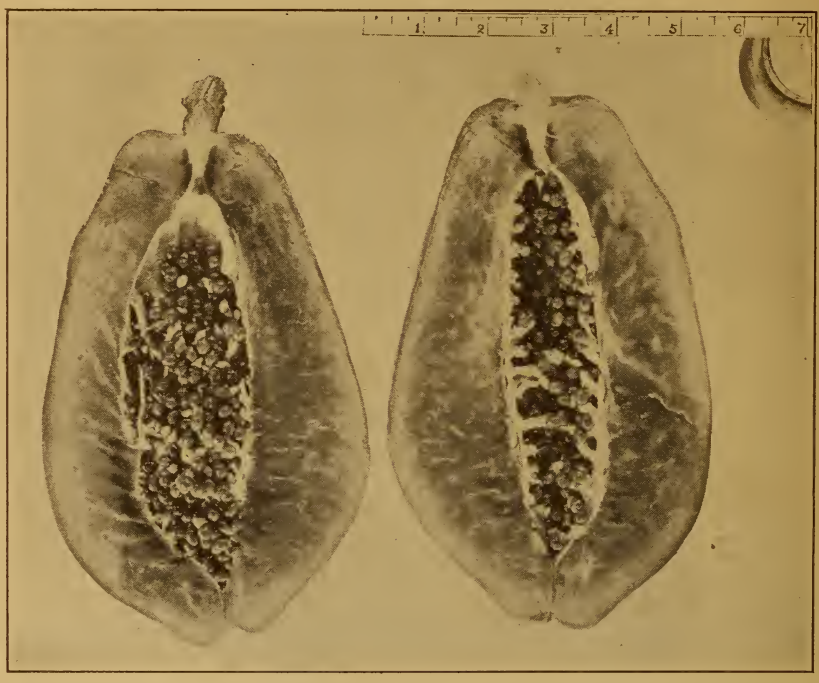

FIGURE 24.—The red-fleshed papayas developed on a plant normally producing yellow-fleshed fruits. These two fruits were also of different shape and flavor from the rest of the fruit on the same tree

CUTTINGS

Growing papaya plants from cuttings has been successfully accomplished in several countries. Its possibilities have been demonstrated at the station on several occasions. Probably the most successful experiment at the station in recent years was that made in 1923–24, when cuttings varying from one-half to 3 inches in diameter and from 6 to 24 inches in length were used. The cuttings are made from side branches which are taken from the trunks of vigorous fruit-bearing plants. Some plants fail to produce these lateral branches, but they usually will do so if the terminal growth is cut off. The basal ends of cuttings should be at the nodes. Entire branches root better than sections and give a more natural form of mature plant. Entire branches when used should be removed from

the parent plant so as to leave the natural enlargement on the basal end of the cutting. At this point the tissue is fairly hard and will tend to root without decaying if the surface is smoothed with a sharp knife. The inner tissues of the papaya plant, if exposed, are exceptionally favorable for the entry, rapid development, and spread of destructive fungi. Cuttings, particularly when sections of branches are used, should be dried for a day or two to heal the cut surfaces. The exposed cut surface of the stems of such cuttings above ground should be capped with a small amount of grafting wax. All large leaf blades should be removed, leaving only petioles several inches in length. This prevents undue transpiration from taking place and thus keeps the cuttings from wilting. The petioles will soon drop and leave leaf scars which will heal before fungi have time to enter them.

FIGURE 25.—A 2-year-old plant which has flowered freely but has produced no fruit just coming into bearing

At the station the cuttings were rooted in different mediums, such as coral, beach, and black volcanic sand, and well-decomposed lava soils. Trials in these soils were made in the propagating house, in open benches several feet above ground in the nursery, and in the field, Trials in the field were made in both decomposing tufa soils and basaltic soils. All the trials were made without bottom heat. The time required to produce sufficient roots for transplanting the cuttings varied from two to five months. This period probably could have been reduced considerably by the use of bottom heat, such as has been advantageously applied in the rooting of some other kinds of cuttings. Whole branches used as cuttings will begin to send out new leaves from the terminal buds a few days after being set. These leaves, which are produced mainly from the reserve nutriment in the tissues of the cuttings, will continue to grow, and will cause that section of the trunk supporting them to become stunted if the roots

are slow in developing. In most instances the plant fails to enlarge sufficiently in any later period of growth. The newly formed roots of papaya cuttings are very delicate and form a fine network which is easily broken in transplanting. (Fig. 27.)

Where transplanting is necessary, the cuttings should be rooted in individual containers and taken up with the least possible disturbance of the roots in the mass of soil. The highest percentage of successes obtained under the conditions employed was with cuttings about 2 inches in diameter and 24 inches in length. These had been set to a depth of 10 or 12 inches in coarse, basaltic sand (volcanic cinders). It was observed that this method of rooting does best during the cooler months of the year. (Fig. 28.) The results of the experiment, considered in their entirety, did not indicate that the propagation of the papaya by means of cuttings is of much practical value.

FIGURE 26.—Seedling papayas ready for potting preparatory to being set out in about eight weeks' time

GRAFTING

Successful experiments in grafting the papaya have been reported from various parts of the world. Fairchild and Simmonds (*6*) conducted some interesting experiments in grafting the papaya during the several years previous to 1913. Their greatest success was attained in grafting small seedlings about 8 or 10 inches high, using scions 3 or 4 inches long and about the diameter of a lead pencil, which were lateral branches of seedling trees known to produce choice fruit. The large percentage of successful grafts, their rapid growth, and early fruiting habits indicated great possibilities. Later investigations in Florida, however, showed that when the papaya was propagated in this way continuously for three or four generations the variety degenerated rapidly. The grafted plants failed to make vigorous growth, and the fruit remained small and inferior in quality. No explanation of this behavior seems as yet to have been made. The condition is very similar to that which takes place in the short

life of the seedlings, and has been observed in papaya plants propagated from cuttings, grafts, and seeds in Hawaii. It appears as a natural old-age condition of an herbaceous, short-lived plant. The cuttings and grafted plants possibly carry and transmit the age limit as they do other varietal and specific characters of the original seedlings. Wester (*23, p. 57–59*), who made rather extensive experiments in grafting tropical plants in the Philippines, briefly described cleft and side grafts successfully made with the papaya, but he did not discuss the practicability of vegetative propagation.

FIGURE 27.—The rooting of a cutting is slow and the newly formed roots are very fibrous. This method of propagation is unsatisfactory for commercial fruit production

Grafting experiments with the papaya were continued for about four years at the station. The plants used varied from small-pot size to field-grown plants of about 6 months of age. Where pot-grown plants were grafted, young seedlings about 2 inches high were transplanted from the flat to 3½-inch pots of rich, sterilized soil. After a day or two in the slat propagation house for partial shelter from the sun, they were put on benches in the open nursery in the full sunlight to enable them to make rapid and stocky growth. They were kept far enough apart to avoid spindling growth. Grown in this way, they required about 40 days to reach suitable size for grafting. At this age the stems of the young seedlings were easily grafted. The methods of grafting tried were the cleft-graft and the whipgraft. In the cleft-graft method the seedling is cut squarely off with a sharp knife at a convenient point above ground and where it is desired to insert the scion. The stump is then split down about 1 to 1½ inches. The scion is cut to a long wedge at the basal end and then pushed down firmly into the cleft of the stock; for further security the union is bound with raffia. The leaf blades of the larger leaves are clipped off to retard evaporation. This form of union is used only where the seedling and the scion are small and have not formed the hollow cavity which develops in larger papaya stems. Uniformity in size of stock and scion is not so important in grafting small plants as in the larger ones. However, the scion should not be larger than the stock.

The whipgraft method differs from that of the cleft-graft only in form of union and should receive the same care as the latter. The cut surfaces of stock and scion are beveled off to about an inch in length. Tongues are cut in these surfaces to aid in holding the united parts together. The union is then bound with raffia. The two kinds of grafted plants should be shaded in the slat propagation house for three or four days and then given full sunlight. The binding should be removed in about a week's time, and as soon as the union seems to be thoroughly healed the plants should be set in their permanent place in the orchard.

The object of the field experiment with large dioecious papaya plants was to determine the possibilities of changing the staminate, nonbearing plants into fruitful ones. The seedlings used were grown for the first six weeks in tin containers. They were then set in orchard form on September 15, 1920, and began to bloom in two and one-half months. Among these seedlings, which were of stock that had been improved at the station by seed selection for a number of generations, the male or staminate plants constituted 36 per cent. A number of these were grafted in January, 1921. At this time the seedlings had an average height of 4 feet, and a trunk diameter ranging from 2½ to 4 inches, measured 1 foot above the ground. The graft unions were made at various heights from 2 to 3 feet above the ground, the place of each being determined by the size of the individual scions provided for the work. Scions a foot or more in length were taken as lateral branches from good fruiting plants. These were difficult to obtain. However, such growth was obtained by topping back the parent plant, which resulted in a forced growth of lateral branches. The methods of grafting used were the saddle graft and the whipgraft. The former gave the best results, as the stock and the scion tend to make uniform growth all the way around the stem. Openings leading into the central cavity are sometimes formed in the

FIGURE 28.—A papaya plant grown from a cutting some 2 inches in diameter which rooted when set in soil of decomposing volcanic cinders

healing of the graft union. These tend to weaken the trunk and may admit destructive fungi, which may prove to be fatal to the plant. Some successful unions were made with whipgrafts. (Fig. 29.) Grafted plants came into fruit from four to six months after the unions were made. During the remainder of their existence most of the grafts had periods of slow growth which were indicated by constricted sections of trunk with nodes more closely packed. Growth was not vigorous, and fruit production was not abundant. By January, 1924, all the grafted plants had died from lack of vigor. The results of the experiment indicated the impracticability of trying to change the sex of papaya plants by means of grafting them in the field.

FIGURE 29.—Grafting the papaya is not difficult, but it is generally unsatisfactory

CULTURE

NATURAL REQUIREMENTS

In Hawaii the papaya thrives best at altitudes below 1,200 feet, luxuriating and producing its best fruit in the warmest localities (*9*, *p. 7–8*). The effect of the lack of heat in the cool season is shown by the slow growth and the setting of less fruit, and also by a retardation of the processes of growth and ripening of the fruit. Fruit produced at high altitudes or that maturing during cool weather fails to reach its normal color and the flesh also is pale and of insipid flavor. Papaya plants when grown in warm and somewhat sheltered sections often appear to be more or less dwarfed in form and begin fruiting at an early age. (Fig. 30.) The plant, however, eventually reaches normal height. In regard to rainfall and moisture requirements, the plant is able to adapt itself to a wide range of conditions, and when well established suffers much less from a shortage of moisture than do many other kinds of fruit trees. The plant makes beneficial use of large amounts of water when it is supplied. Light, misty rain, blown continuously, or nearly so, by trade winds for several days, as occasionally takes

place in parts of Hawaii, often prevents natural pollination and results in failure of the fruit to set. At such times some fruit may set without pollination, the result being seedless forms which are

FIGURE 30.—Dwarfness is believed to be influenced by environment, although these two plants of the same age came from seed of the same fruit, indicating that dwarfness may be a mutating quality

usually of poor quality. (Fig. 15.) The papaya will thrive on soil that is regarded as too shallow to be suitable for most other fruit trees. The papaya plant grows equally well in volcanic soil of either basaltic or tufa origin, particularly where it is in alluvial deposits

on the lowland plains. There are few, if any, soils in Hawaii in which the papaya will not grow, but the plant is insistent in matters of adequate underdrainage and aeration. In water-logged soil the papaya makes spindling growth and drops its lower leaves prematurely, while the remaining foliage turns yellow and the whole plant becomes unhealthy. The papaya, like practically all other cultivated fruit trees, gives better results if it is grown in a deep, rich well-drained soil.

PLANTING

Before the papaya is planted in commercial orchards, the land should be cleared, thoroughly plowed, and harrowed. It should then be staked for rows at right angles 10 feet apart each way. Setting the plants at the intersections will permit of planting 435 to the acre.[5] Holes for planting should be dug about 3 feet across and 18 inches deep to allow the young plants to make their early and most delicate root growth in a properly made-up soil. The holes should then be filled with thoroughly mixed surface soil which has been incorporated with one-fourth part of well-decomposed barnyard manure. The latter adds organic matter, nitrogen, and some other essentials which stimulate vigorous growth. The small plants of sturdy growth, 6 to 10 inches high, should be removed from the individual containers and set in the made-up soil, two plants being placed 18 inches apart in each hole. In this planting the soil is firmed around each plant so that the immediate surface will be 1 or 2 inches below that of the field. Immediately after planting is done the plants should be moderately watered. They should be watered every day or two for a few weeks and then given a liberal watering once a week whenever the rainfall is insufficient for growth. The plants must be kept growing vigorously. Such short-period crops as peanuts, onions, and tomatoes, may be grown between the papaya rows during the first six months. In five to seven months from the time the plants are set they will begin to blossom, and the sex can then be determined. Most of the staminate plants should be removed and only one pistillate plant left in each hole. The method of planting two plants to the hole reduces the probable production of too many nonbearing or staminate plants. Some plants should be kept in reserve for use when both plants in a hole prove to be staminate or otherwise undesirable. At least one staminate plant should be left to each 50 pistillate plants in the grove to assure sufficient pollination to set fruit.

Where the monoecious type of papaya is grown it is not necessary to set two plants in each hole, but extra plants should be held in reserve to replace undesirable plants or misses. The monoecious type nearly always produces some plants which either are sterile or produce poorly shaped fruit. Proper pollination is necessary to develop an abundance of well-formed and good-flavored fruit. To assist in establishing these qualities, even in groves of the monoecious type, growers in Hawaii usually maintain several staminate-flowered plants on the windward side of the grove. Papaya plants when set

[5] In some parts of the Territory where the moisture supply is limited and vegetative growth is less vigorous, growers set the plants 8 feet apart, which permits of planting 680 plants per acre.

in rows at right angles may be easily cultivated and irrigated when necessary. This arrangement is also convenient in picking the fruit.

During the first year the plants may be watered in depressions about the base of the trunk. These depressions should be filled and firmed down previous to the occurrence of the heavy rains and winds of the wet season to prevent the plants from being blown down. After the first year the cultivation should be carried on above the feeding roots which will then have extended out in the soil in all directions several feet from the trunk. Water should then be applied above the feeding roots in a moatlike basin several feet from the base of the trunk. Plants which are allowed to stand in large basins for several years invariably go down in windy weather, particularly when they are loaded with fruit. The moat about a plant need not be large. A shallow trench 2 or 3 inches deep and 12 or 18 inches wide, circling the base of the trunk at a distance of 2 or 3 feet from it, depending on the size of the plant, will do. Commercial orchards should be discontinued in three or four years after they have begun to fruit. The best and largest amount of fruit is obtained from young plants 2 to 4 years of age.

IRRIGATION

The papaya responds to irrigation much as it does to natural rainfall. Under the widely varying conditions existing in Hawaii, it is impossible to give any definite rule governing the amount of irrigation to be used. With a uniform supply, which may vary from 25 to 50 inches of rainfall evenly distributed weekly throughout the year, the plants naturally fruit abundantly and continuously for possibly three to five years or more. Irrigating, when practiced, should be done with considerable care in order that fruit of the best quality may be produced. Insect enemies, particularly red spiders, are more likely to attack the foliage during irrigation periods than at other times. It has beeen found that in general the amount of water required is not nearly so great for the papaya as for most other orchard crops. In many groves on dry, leeward lowlands, water should be applied liberally about once a week in shallow basins or furrows between the rows. The hillside groves should be watered in somewhat the same manner, but the plant rows are arranged along contour lines to accommodate both irrigation and cultivation.

FERTILIZING

The addition of barnyard manure to the soil in which the papaya is growing has been found to be beneficial at the station. In addition to the light application incorporated at the time of planting, 5 to 10 pounds have been worked into the surface soil around each plant about twice a year. This form of fertilizer adds plant food, improves the water-holding capacity of the soil, and encourages beneficial bacterial action. Good results have followed the use of a fairly complete chemical fertilizer having the following formula:

	Pounds
Superphosphate (acid phosphate)	800
Sulphate of potash (high grade)	315
Nitrate of soda	250
Sulphate of ammonia	190
Black volcanic sand	445

One pound of this fertilizer was worked into the surface soil around each young plant twice, at intervals of six months, during the first year. Later applications of 2 pounds per tree were made as the plants grew larger. The fertilizer tends to promote vegetative growth, which is necessary in producing a good quality of fruit.

THE CROP

TIME OF MATURITY

Papaya plants which have received good culture will begin to ripen their first fruit in 10 to 14 months from the time the plants are set in the orchard under Hawaiian conditions. The production is practically continuous during the several years of vigorous life of the plant. In the cooler months growth and maturity of the fruit are somewhat retarded. This results in a shortage of fruit on the markets and high prices for a month or two during the so-called winter season. Papayas attain their best qualities if they are allowed to remain on the plant until very nearly ripe, when they turn from green to yellow. Green papayas have a very limited use. Fruits of some plants growing at an elevation of more than 500 feet are often ripe and of good flavor before the outside color has developed beyond light green.

HARVESTING, HANDLING, AND MARKETING

Papayas may be easily picked by giving them a careful twist with the hand. Fruit which can not be readily reached from the ground may be picked by means of stepladders and specially adapted long-handled pickers. For general marketing purposes the fruit should be picked as soon as it shows its first trace of yellow. The fruits are so large and heavy and of such delicate structure that it is difficult to get them to the consumer in good condition, particularly if they have begun to soften when picked. The greatest care should always be used to avoid bruising. The fruit should be transported on a bed of straw or some similar material in a spring conveyance. An abundance of packing material should be used to separate the tier crates from one another. In marketing investigations which were conducted by the station in 1907, it was found that papayas can be successfully shipped comparatively long distances in cold storage. Selected fruit was marketed in small quantities in San Francisco, Portland, Seattle, Tacoma, and also in Vancouver, British Columbia. The long-shaped fruit with the small central cavity carried best. (Fig. 3.) Each fruit was wrapped in paper and surrounded by a sleeve or cylinder of corrugated strawboard and then packed in single-tier crates holding four to six fruits. This experiment had hardly been completed when the Mediterranean fruit fly appeared in Hawaii and Hawaiian fruits were restricted by quarantine from entering coast ports. New methods are being devised for preserving the fruit so that it will not be subjected to quarantine, and increased interest is being taken in the possibilities of exporting the papaya to markets outside the Territory.

YIELDS

The papaya is recognized as an enormous producer. Definite data on this point are of little value, however, because the papaya varies greatly in yields in different localities. Variation is due to many conditions of climate, soil, methods of culture, and the like. Records of several small plantings at the station for the first eight months after the plants came into fruit are given in Table 1.

TABLE 1.—*Yields of papayas at the Hawaii station for the first eight months after the plants came into fruit*[1]

Accession No.	Shape	Plants	Total time of fruiting	Weight of fruit per plant	Total weight
		Number	*Months*	*Pounds*	*Pounds*
4617	Round	31	8	36.25	1,124
4616	do	28	7	25.00	700
4618	Long	38	8	19.25	731
4619	do	33	7	28.00	924

[1] The plants were set 8 by 8 feet, permitting 680 to the acre.

ENEMIES

Insects, birds, and plant diseases give very little trouble to the papaya grower in Hawaii. Occasionally the red spider is reported as attacking the plants. Its presence is usually indicated by a yellowing of the foliage. The pests themselves may be found in small scattered colonies on the under sides of the leaves. Red spiders, or mites, are also occasionally found in masses on the surfaces of the maturing fruit. The skin of the fruit then becomes roughened and of a very unnatural brownish color. The mite and its destruction of the plant tissues can be accurately detected only by means of a magnifying glass. Ordinarily this pest seems to be held in check by several kinds of predacious insect enemies. Attacks by the red spider may be controlled by dusting dry, powdered sulphur on the under surface of the leaves with a sulphur blowgun. Mediterranean fruit-fly maggots have been reported by entomologists as occasionally found in papayas which ripen on the plant. It has been observed, however, that eggs which are laid in the green fruit are rendered inactive by the strong outward pressure of the acrid, milky juice which gushes from the wound. Ordinarily the fruit is harvested when it is firm in texture and beginning to show the ripening color. There is then little or no chance of its being infested. Neither of the above-mentioned enemies is considered to be injurious in the sense of seriously affecting the crop. The mynah bird occasionally eats parts of the ripening fruit, particularly when it has difficulty in getting other food. One or more forms of fruit rot have been reported in Hawaii, but they apparently develop only at times of unusual climatic conditions. One form affects the apex, or stigmatic point, of the fruit. The disease may injure a number of the fruits, but the period of attack is usually of short duration. An application of dilute Bordeaux mixture has been recommended for its control.

COMPOSITION OF THE FRUIT

A number of analyses of the fruit of the papaya have been made at the station. In 1914 Alice Thompson (*20*) analyzed ripe papayas of plants that were designated by the names of the countries whence the seeds had been obtained several years previously. These kinds soon lost their identity as such, however, and they have since been known at the station only by accession numbers. Table 2 gives these and other analyses of the papaya.

TABLE 2.—*Composition of the papaya*

	Total solids	Ash	Acid as H_2SO_4	Protein [2]	Sucrose	Reducing sugars [3]	Total sugars [4]	Fat	Fiber
GROUP A [1]									
Strain:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Trinidad (2976)	12.14	0.530	0.060	0.430	0.74	8.98	9.72	0.060	0.780
South African (2973)	13.00	.540	.090	.680	.53	10.20	10.73	.070	.810
Honolulu (2355:3)	12.20	.560	.070	.500	.00	10.29	10.29	.050	.660
Barbados (2848)	11.72	.480	.060	.460	.00	8.95	8.95	.060	.760
Panama (2978)	14.41	.900	.140	.500	1.26	9.86	11.12	.250	1.090
Tahiti (2975)	10.19	.670	.170	.900	.94	7.50	8.44	.050	.790
GROUP B [5]									
Period of ripening:									
5 to 6 weeks before ripeness	6.48	0.621	0.065	0.800	0.23	2.15	2.38	0.205	0.873
Do	6.13	.451	.045	.381	.00	2.88	2.88	.186	.602
4 weeks before ripeness	6.13	.427	.045	.388	.23	2.81	3.04	.188	.662
3 weeks before ripeness	6.26	.471	.026	.306	.00	2.93	2.93	.208	.716
2 weeks before ripeness	6.45	.425	.044	.306	.47	4.13	4.60	.261	.581
8 days before ripeness	8.92	.508	.033	.356	.00	5.99	5.99	.163	.654
1 day before ripeness	10.68	.514	.059	.468	.47	7.82	8.29	.168	.592
Ripe	10.59	.565	.059	.388	.00	8.02	8.02	.186	.693
GROUP C [6]									
Station accession No.:									
4610	16.27	0.687	0.140	0.548	0.38	13.38	13.76	0.148	0.827
4609	14.44	.778	.134	.501	.83	10.14	10.97	.092	.947
4618	11.05	.688	.131	.454	.38	8.43	8.81	.099	.818
4509	11.78	.887	.124	.449	.30	8.60	8.90	.080	1.255

[1] Analyzed in 1914.
[2] Protein amounts to nitrogen times 6.25.
[3] Reducing sugars expressed as invert sugars.
[4] Total sugars—the sum of sucrose and reducing sugars.
[5] Fruit analyzed at different stages of ripeness in 1914.
[6] Analyzed in 1922.

The early analyses of the papaya had two leading objectives—to show the comparative composition of ripe fruit of a number of seedling strains (Group A) and to study the composition of fruit ranging from half-grown to fully ripe specimens on a given plant (Group B). The papaya, although containing little nourishment, is important for its fruit acids, enzymes, and high water content. The leading enzyme, papain, is of particular interest because it is allied to pepsin and is considered an aid to digestion. A study of Group B shows that the green fruit contains practically no starch or sucrose and that the reducing sugars are low in the green fruit, but rapidly increase as the fruit approaches ripeness. Fruit of the plant known at the station as No. 4610 (fig. 21) was found to be high in carbohy-

drates in 1922 and particularly sweet in flavor, but seed of this plant produced plants with fruit of poor quality. The fruits listed under Group C were analyzed in 1922, and were selected from plants that had been improved by seed selection over a period of several generations. It is believed that the quality of the fruit is in general superior to that referred to under Group A, but a comparison of the data shows nothing unusual as regards composition.

USES

AS FOOD

The ripe papaya is most extensively used in Hawaii as a breakfast fruit. For this purpose it is cut lengthwise into individual portions, and the seed is removed. The fruit is served like the muskmelon, being flavored to suit the taste by the addition of lime juice, salt, pepper, or sugar. It is sometimes served as a fruit cocktail at either luncheon or dinner, and as a dessert it is sliced and eaten with sugar and whipped cream. Combined with lettuce and mayonnaise, the papaya makes an excellent salad. It is good as a crystallized fruit and is sometimes made into pickles, marmalade, jelly, pie, and sherbet. The green fruit may be boiled or baked and served as a vegetable much as is summer squash. Many recipes for the use of the papaya are given in Hawaiian cookbooks. A few of the more simple recipes are here given for the use of the fruit (*21, pp. 42–43*).

PAPAYA COCKTAIL

Cut papaya in dice and serve in glasses with cocktail sauce and chipped ice. Or serve with orange, lemon, or lime juice, and little sugar in same manner.

PAPAYA SALAD NO. 1

On a strip of peeled papaya lay small bits of pomelo and orange. Serve with mayonnaise on separate plates, and garnish each with one or two nasturtiums and leaves.

PAPAYA SALAD NO. 2

Cut papaya in cubes and add eight small onions and five pieces green celery chopped fine. Serve with boiled dressing.

PAPAYA WHIP

To 1½ cups papaya pulp add juice of 1 lemon, ½ cup sugar, and beat into 2 stiffly whipped whites of eggs.

PAPAYA PICKLE

Make sirup of 1 measure sugar and ½ measure vinegar. Add a few whole cloves and peppercorns and 2 measures of half-ripe papaya cut into small pieces. Boil until tender.

ORANGE AND PAPAYA MARMALADE

To 1 measure papaya allow ½ measure oranges. Wash oranges well. Squeeze out seeds and juice. Put skins through a meat chopper and add to the juice, strained free from seeds. Add papaya pulp cut in small pieces [without rind] and boil all together; then add as much sugar as pulp. Boil again for 15 or 20 minutes.

PAPAYA-FLAVORED GELATIN DESSERT

½ box gelatin	1 cup boiling water
½ cup cold water	1 cup papaya pulp
Juice 1 lemon	½ cup sugar

Soak gelatin in cold water five minutes. Dissolve the sugar in the boiling water; add the gelatin and strain. When cool, add the papaya and lemon juice. Place on ice to harden.

PAPAYA AND GINGER

Make a sirup of 1 measure sugar, ½ measure water, some finely sliced dried ginger, and a few slices of lemon. Add 2 measures half-ripe papaya sliced lengthwise, which has been previously simmered in water until clear but not broken.

PAPAYA PIE

2 eggs	1 cup sugar
1 cup papaya pulp	Juice ½ lemon

½ cup butter

Make a bottom pie crust and bake. Cream butter and sugar. Add beaten eggs, lemon juice, and papaya. Pour into pie crust and bake. Make a meringue of whites of eggs and 2 tablespoonfuls sugar. Place on pie and brown in oven.

PAPAYA SHERBET

Mix 4 cups papaya pulp with 2 cups sugar and juice of 2 lemons and freeze.

STEWED PAPAYA NO. 1

2 cups diced papaya	¼ cup water
½ cup sugar	Juice of 2 lemons

Cut papaya in dice and stew with sugar, water, and lemon juice ½ hour. Serve in sherbet glasses as a first course for luncheon or a dessert. Can use 4 oranges in place of lemons.

STEWED PAPAYA NO. 2

Cook in the same manner as No. 1, with ¼ cup sugar and only enough water to keep from burning. Serve as vegetable.

BAKED PAPAYA

Cut papaya in halves lengthwise. Add a little sugar and orange, lime, or lemon juice, or a little cinnamon in place of the juice. Bake 20 minutes and serve immediately on taking from the oven. This is a vegetable.

MEDICINAL AND OTHER USES

Nearly all parts of the papaya plant are said to have some medicinal value. The most important medicinal properties are found in the milky juice, which occurs most abundantly in the green fruit. Most of the medicinal properties of the juice are due to the active principle called "papain." This enzyme greatly resembles animal pepsin in its digestive action and has been recognized as of considerable "value as a remedy in dyspepsia and kindred ailments" (*16, p. 229*). The digestive action of this enzyme has long been recognized in the Tropics, where it is not an uncommon practice to rub a slice of green juicy papaya on tough meat to make it tender. Sometimes a piece of the green fruit is put in the water in which the meat is boiled. Another practice is to wrap the meat in crushed papaya leaves overnight preparatory to cooking it.

The production, preparation, and properties of papain for commercial purposes have been thoroughly studied and discussed by various writers, including Kilmer (*11, p. 383 395*), Pratt (*17*), Cunliffe (*4, p. 25*), Macmillan (*13*), and Chesnut (*3*).

PAPAIN

The collection and preparation of papain as briefly described by Higgins (*9, p. 17*) is as follows:

There are no difficulties requiring great skill in collecting and preparing the juice for market, but care is necessary. Usually only the fruits are tapped. These abound in juice, particularly when the tree is young and during warm weather after a rain. In the early morning the flow is most abundant. Very shallow incisions, not over one-eighth of an inch, are made about a half inch apart, lengthwise of the nearly mature green fruits. The tapping may be repeated several times at intervals of three or four days. Only nonmetallic instruments should be used in tapping or in collecting, for the juice acts upon metals and becomes discolored. A bone or ivory blade may be used. The flow is free at first and the liquid is caught in porcelain, glass, or earthenware vessels. Coagulation soon begins and the mass must be scraped from the surface of the fruit. In most places where the industry is conducted labor is cheap, but it would seem that a more convenient and efficient vessel could be devised which could be quickly put in place to receive the juice, permitting the operator to proceed to the next tree.

The juice must be dried promptly after it is collected or decomposition begins. As the juice flows most freely in the early morning, it is usually collected then and dried wholly or in part during the remainder of the day. Sun drying is followed to some extent, but artificial means, such as are furnished by a fruit drier or one made expressly for the purpose are preferred. In Montserrat several driers have been made for the purpose and operated by the companies buying the juice from the peasants who gather it.

One form of drier is about 3 by 3 feet, and 6 feet in length. The sides and ends are of brick with an opening at one end for the flue and at the other end to admit fuel. The top is open. About a foot below the top a sheet of iron is placed and upon this an inch or two of sand to modify and distribute the heat arising from the fire beneath. The coagulated juice is spread upon brown linen stretched upon frames which are made to fit the top of the drier. The drying must be effected with low temperatures, as great heat destroys the ferment. A temperature below 100° F. is preferred by some operators. The coagulated material may be placed upon sheets of glass while drying. When dry and flaky it may be ground in a coffee mill, preferably while warm, and should then be in the form of a white or cream-colored powder, which should be placed in bottles and tightly closed.

In the powdered form or as dried flakes it is exported to America and Europe, where it is further refined and sold as a powder or in tablet or other form under various trade names as "papoid," "caroid," "papain," and "papayotin."

Little information is available as to yields. Some collectors figure upon a yearly production of 1 pound of dried latex per tree. This is probably rather a high estimate. The coagulated latex will produce about 25 per cent of its weight in dried powder which still contains from 6 to 10 per cent of moisture [(*11, p. 338*)]. About one-sixth of the dried powder is papain.

SUMMARY

The papaya, which is believed to be a hybrid of two species of Carica indigenous to tropical America, is widely distributed through most tropical countries. It is known to have been rather widely dispersed in Pacific countries in the sixteenth century. It was known to the Polynesians and probably reached Hawaii in the latter part of the eighteenth century.

The papaya has numerous local names and has been classified in several botanical groups by different botanists, but the name now generally accepted is *Carica papaya*. A specific description is somewhat difficult because of unusual variation. Two leading types based mainly on the essential organs of the flowers which to some extent influence the form of fruit are described in this bulletin.

Results of investigations made at the Hawaii station during the past eight years show that true, established varieties of the papaya do not exist in Hawaii. Variations take place too freely and desirable characters are too unsettled to be stabilized as varieties through mere seed selection and good culture. It is believed that true varieties may be established through carefully conducted crossbreeding in isolation through many generations of the plant. This may eliminate the numerous mutating characters which are undesirable. With present knowledge of the species it is useless to practice vegetative methods of propagation as both environmental and hereditary variations frequently occur.

The papaya is of easy culture but must have good underdrainage, a warm climate, and protection from severe winds. It thrives best in Hawaii at altitudes below 1,200 feet. It is comparatively free from the attacks of insect enemies and plant diseases. The Mediterranean fruit fly rarely attacks the fruit.

Because of the size, weight, and delicate structure of the fruit it is necessary to use great care in its harvesting, packing, and shipping in order to get it to the consumer in good condition.

There is considerable variation in the composition of fruits at different stages of growth and under different conditions of culture. Although the content of nutrients is not high the papaya is highly valued as a food. It also contains an enzyme (papain) which is thought to aid digestion. In Hawaii the ripe papaya is extensively used as a breakfast fruit but may be served in various other ways.

LITERATURE CITED

(1) Bailey, L. H.
1914. The standard cyclopedia of horticulture. 5 v., illus. New York and London.

(2) Candolle, A. de
1884. Origin of cultivated plants. 468 p. London. (Internatl. Sci. Ser. 49.)

(3) Chestnut, V. K.
1920. Report on papain. Jour. Assoc. Off. Agr. Chem. 3: 387–397, illus.

(4) Cunliffe, R. S.
1917. Cultivation of the papaya. Agr. Cuba 1(4): 12–27, illus.

(5) Ellis, W.
1859. Polynesian researches during a residence of nearly eight years in the society and sandwich islands. 4 v., illus. London.

(6) Fairchild, D., and Simmonds, E.
1913. The grafted papaya as an annual fruit tree. U. S. Dept. Agr., Bur. Plant Indus. Circ. 119: 3–13, illus.

(7) Forbes, H. O.
1879. Notes on carica papaya at bantam, java. Jour. Bot. [London] (n. s. 8) 17: 313–314.

(8) Higgins, J. E.
1920. Report of the horticultural division. Hawaii Agr. Expt. Sta. Rpt. 1919: 16–40, illus.

(9) ——— and Holt, V.
1914. The papaya in hawaii. Hawaii Agr. Expt. Sta. Bul. 32, 44 p., illus.

(10) IORNS, M. J.
1908. OBSERVATIONS ON CHANGE OF SEX IN CARICA PAPAYA. Science (n. s.) 28: 125–126.
(11) KILMER, F. B.
1915. THE STORY OF THE PAPAW. Amer. Jour. Pharm. 73: 272–285, 336–348, 383–395, illus.
(12) KULKARNI, L. B.
1915. VARIATION IN THE FLOWERS OF THE PAPAYA. Poona Agr. Col. Mag. 7 (2): 102–112, illus.
(13) MACMILLAN, H. F.
1915. PAPAW AND PAPAIN: THE PRODUCTION AND SALE OF THE DRUG. Trop. Agr. Ceylon 44: 179–184, illus.
(14) ———
1925. TROPICAL GARDENING AND PLANTING, WITH SPECIAL REFERENCE TO CEYLON. Ed. 3, 617 p., illus. Colombo, Ceylon.
(15) MELLO, J. C. DE, and SPRUCE, R. (Communicated by HANBURY, D.)
1869. NOTES ON PAPAYACEÆ. Jour. Linn. Soc. London Bot. 10: 1–14, illus.
(16) POPENOE, W.
1924. MANUAL OF TROPICAL AND SUBTROPICAL FRUITS, EXCLUDING THE BANANA, COCONUT, PINEAPPLE, CITRUS FRUITS, OLIVE, AND FIG. 474 p., illus. New York.
(17) PRATT, D. S.
1915. PAPAIN: ITS COMMERCIAL PREPARATION AND DIGESTIVE PROPERTIES. Philippine Jour. Sci. 10 (A): 1–33, illus.
(18) SOLMS-LAUBACH, H.
1889. DIE HEIMATH UND DER URSPRUNG DES CULTIVIRTEN MELONENBAUMES, CARICA PAPAYA L. Bot. Ztg. 47: 709–720, [725]–734, [741]–749, [757]–767, [772]–781, [789]–798, illus.
(19) STURTEVANT, E. L.
1919. STURTEVANT'S NOTES ON EDIBLE PLANTS. N. Y. State Dept. Agr. Ann. Rpt. 27, v. 2, pt. 2, 686 p, illus.
(20) THOMPSON, A.
1915. THE COMPOSITION OF HAWAIIAN FRUITS AND NUTS. Hawaii Agr. Expt. Sta. Rpt. 1914: 62–75, illus.
(21) TURNER, J., and ALEXANDER, A. B.
1910. HOW TO USE HAWAIIAN FRUITS. 58 p. Honolulu.
(22) WELLS, H. M.
1906. PAPAYA CULTURE IN HAWAII. Hawaiian Ann. 32d Year: 146–154.
(23) WESTER, P. J.
1916. PLANT PROPAGATION IN THE TROPICS. Philippine Bur. Agr. Bul. 32, 87 p., illus.
(24) WILCOX, E. V.
1916. TROPICAL AGRICULTURE: THE CLIMATE, SOILS, CULTURAL METHODS, CROPS, LIVE STOCK, COMMERCIAL IMPORTANCE AND OPPORTUNITIES OF THE TROPICS. 373 p., illus. New York and London.

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